FDTD Seismic Simulation of a Moving Tracked Vehicle

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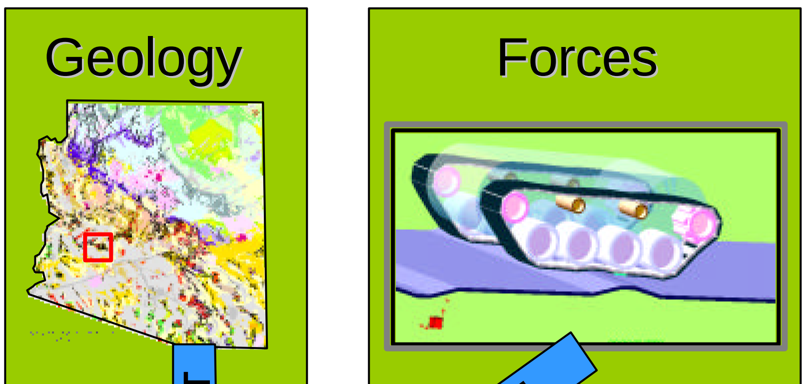
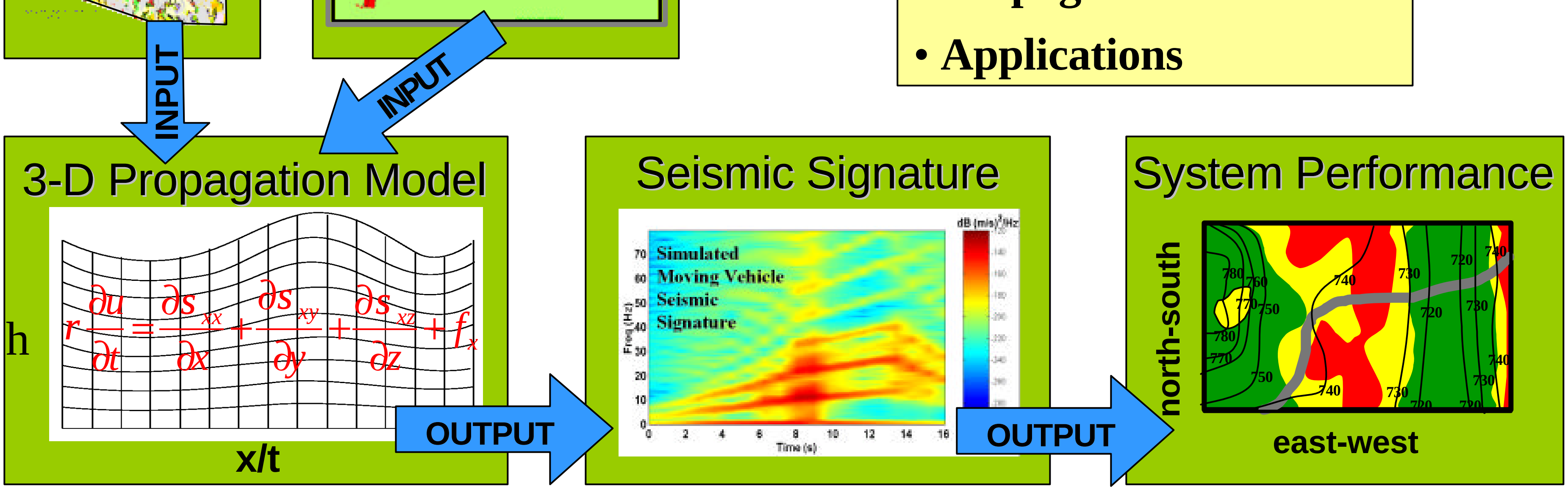
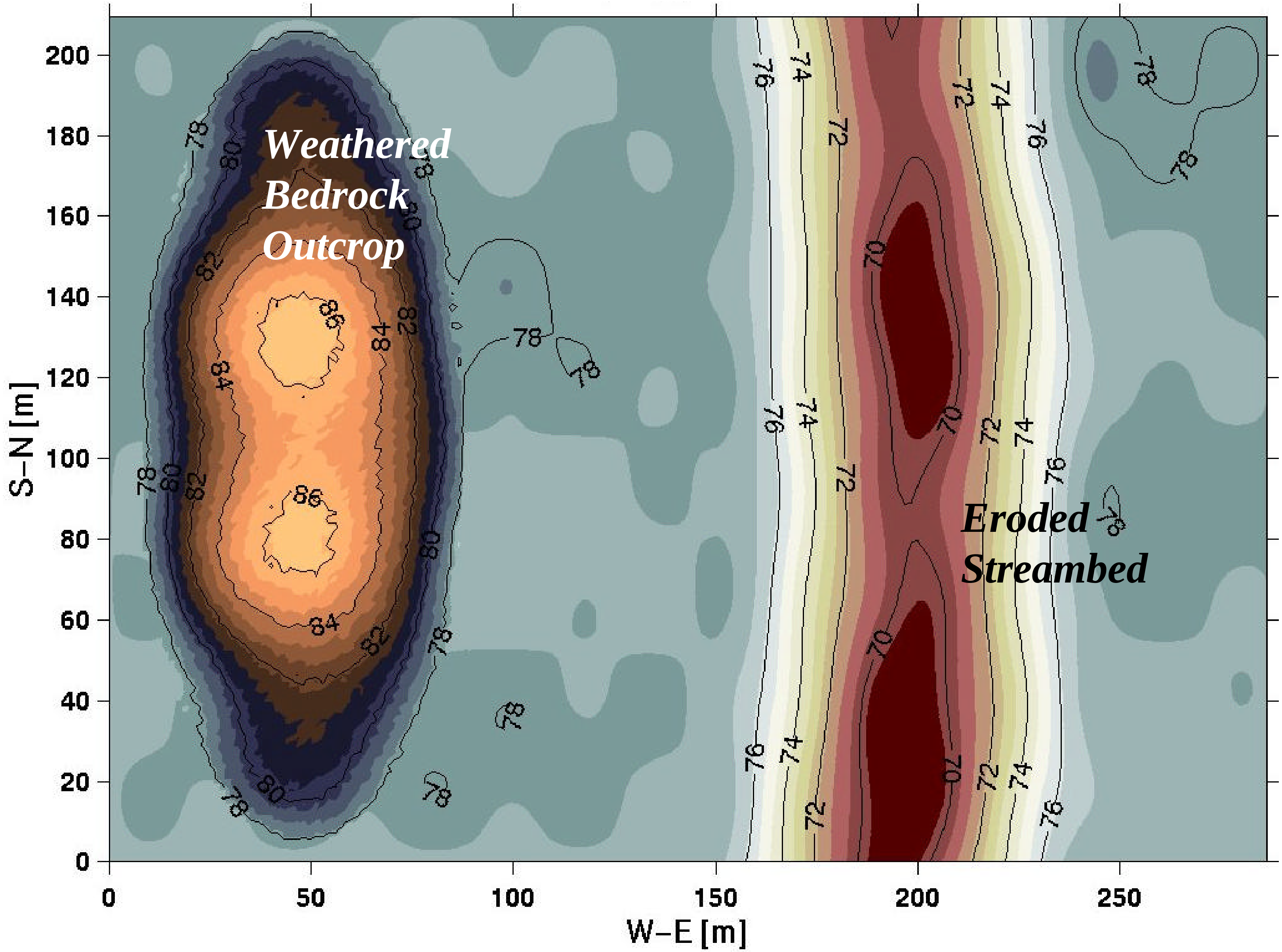


Outline

- **Geologic model**
- **Moving vehicle forces**
- **Propagation results**
- **Applications**



Surface of geologic model



Features

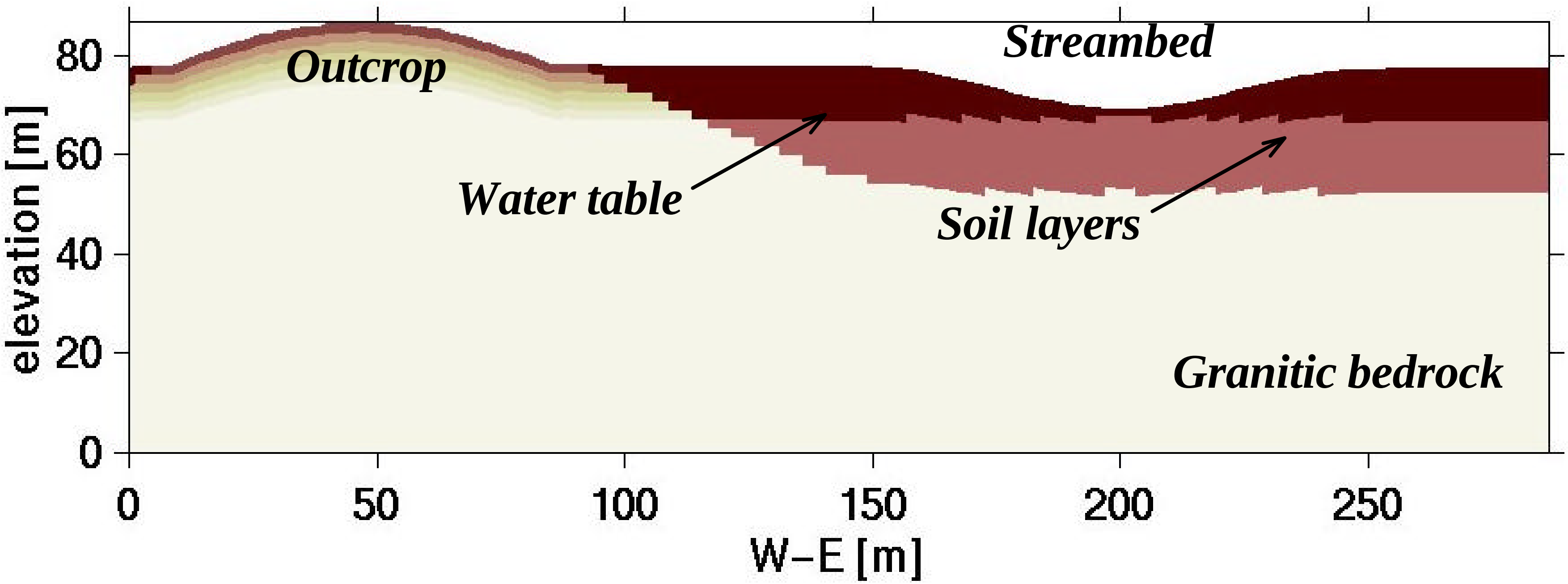
8.5-m-high weathered outcrop

8-m-deep trench

Surface roughness

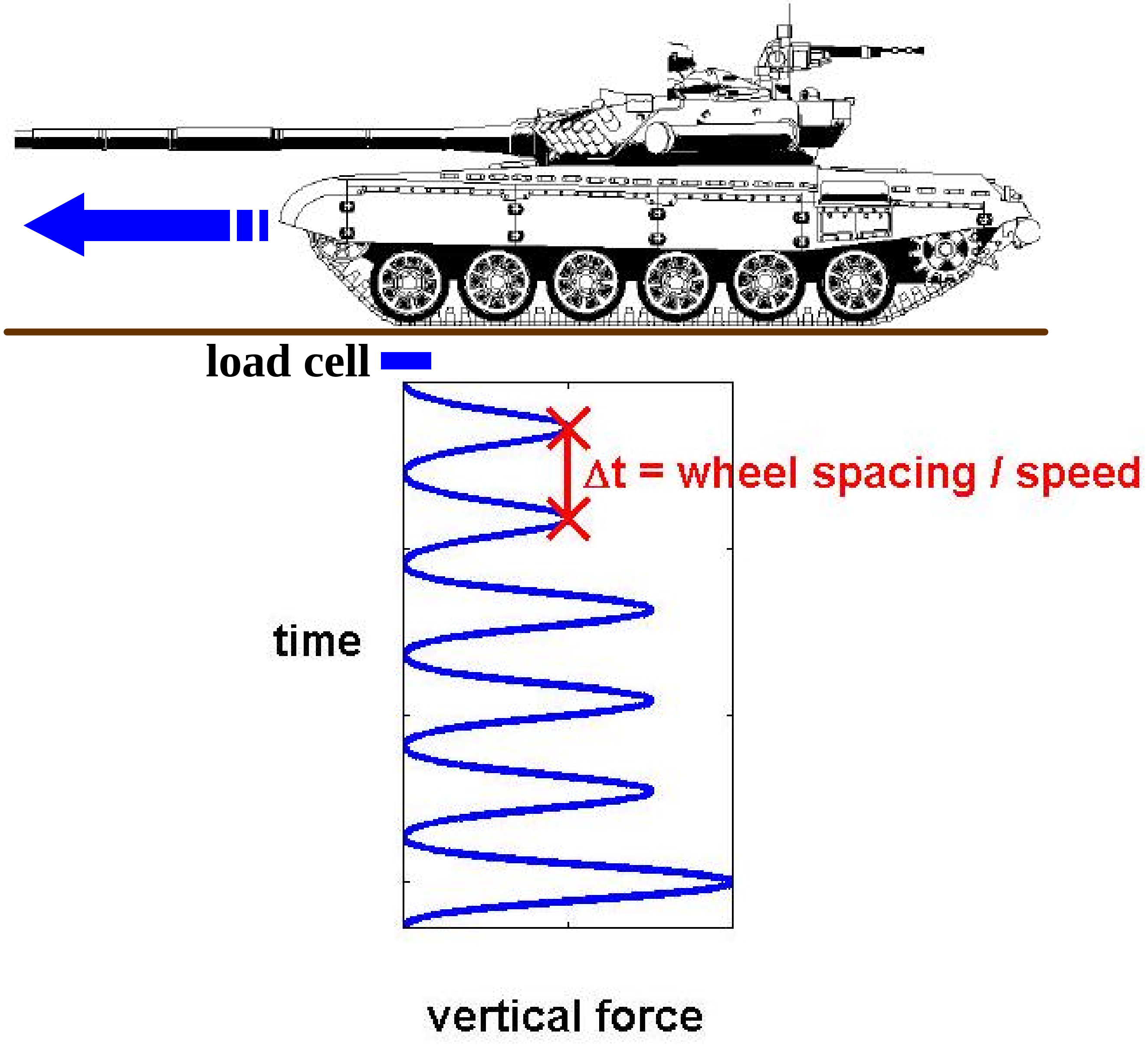
0.002 slope

Model slice at South-North coordinate = 130 m



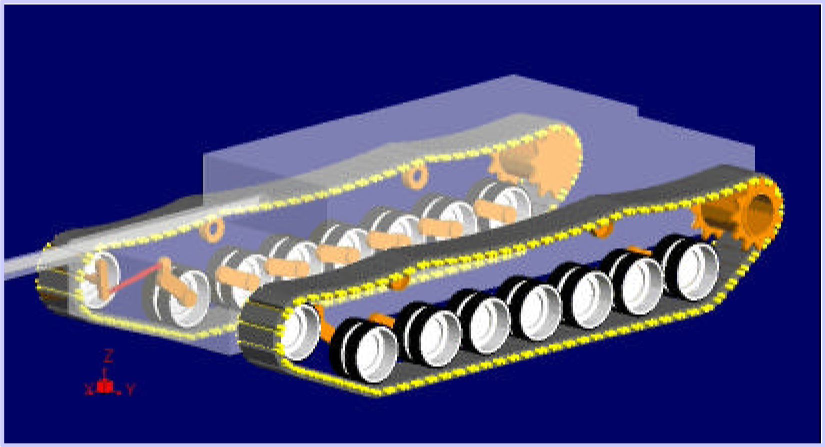
	P-wave speed (m/s)	S-wave speed (m/s)	Density (kg/m^3)	Qp, Qs
Upper soil	1000	577	1750	20, 10
Lower soil	1600	625	2000	30, 15
Granitic bedrock	3500	2333	2650	75, 36

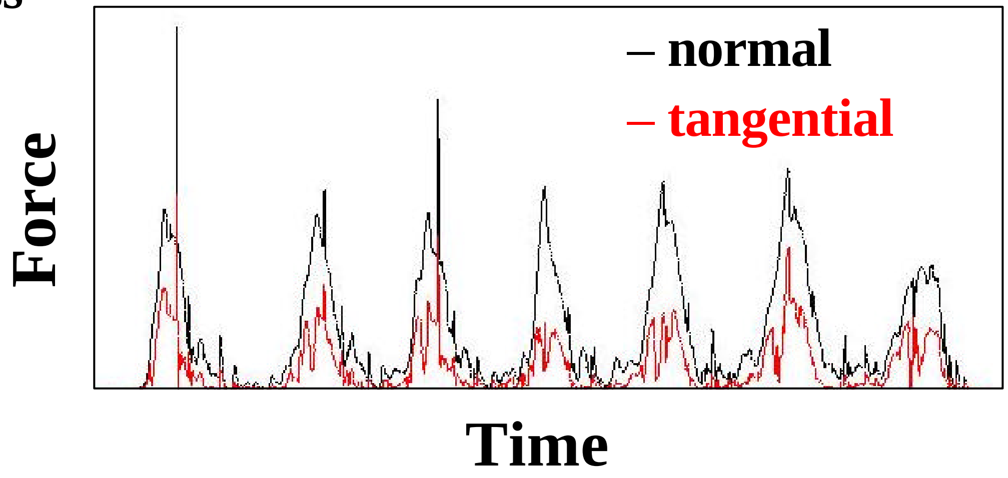
Force inputs from idealized force vs. time record of tracked vehicle



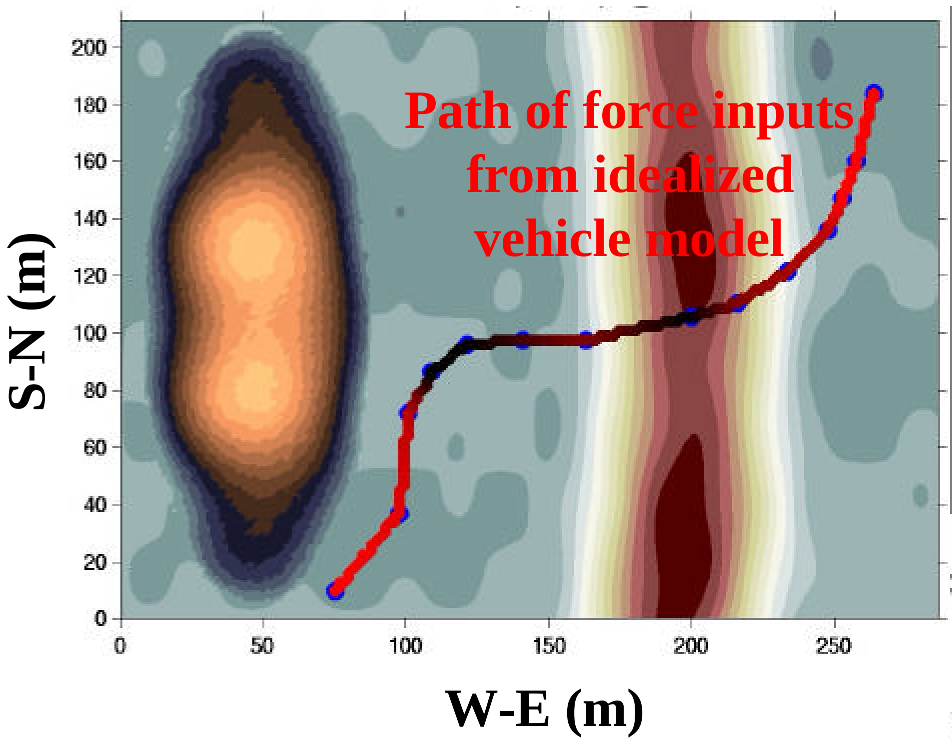
Force inputs from dynamic model of M1A1

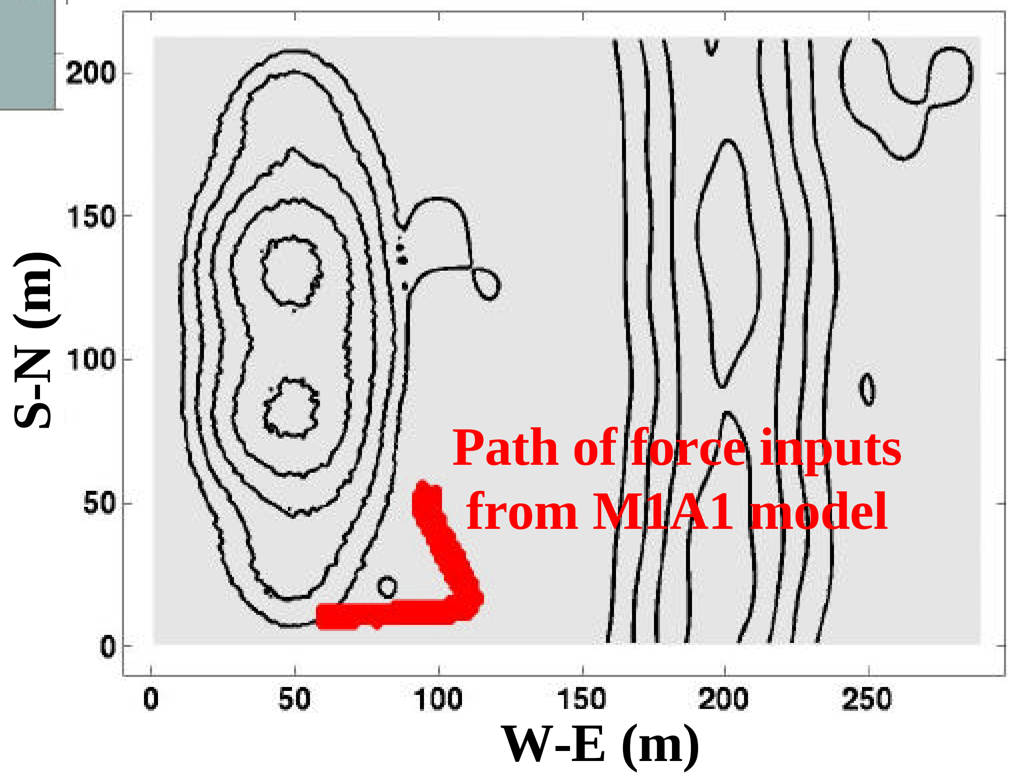
- Track and suspension details emphasized, including:
  - Individual track block & road wheel inertial/mechanical properties
  - Track pin configuration (single or dual)
  - Road arm stiffness and damping
  - Track tension control
- M1A1: 195 bodies, 356 DOF
- Hull & turret are single sprung mass (w/ roll, pitch, and yaw)
- Soil/track reactions included
- Vehicle driven by torque at drive sprockets





Vehicle paths over topographic surface





Propagation modeling

<u>Objective</u>

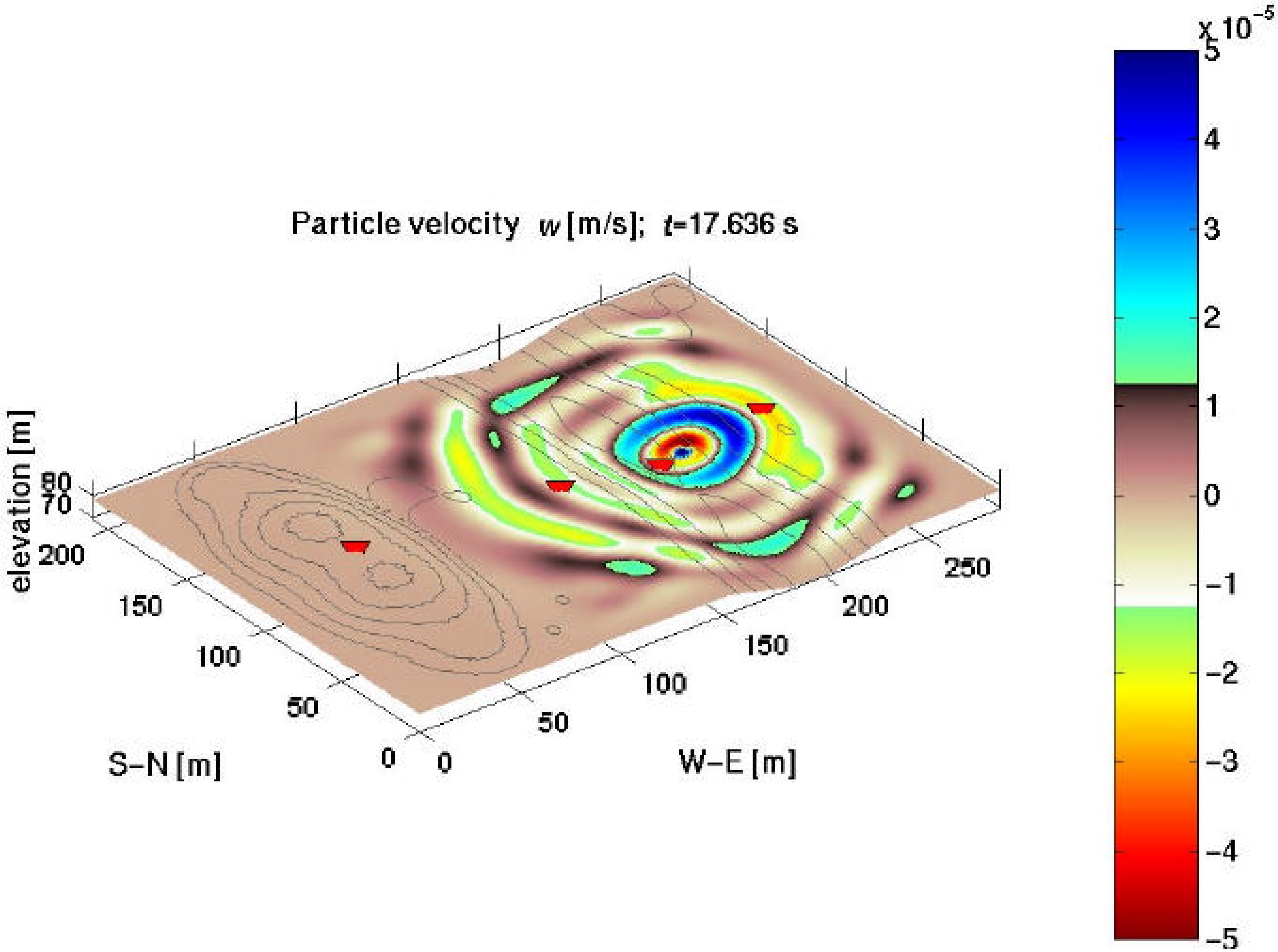
- **Models of sizes for battlefield systems**
- **Propagate Ý Û vehicle ground vibrations to sensors**

<u>Approach</u>

- **AFOSR, FDTD**
- **3-D wave equation**
- **Parallel computations**
- **Soil attenuation**
- **Topography, heterogeneous geol.**
- **Complex ground forcing**

<u>Details</u>

- **1.6-m spacing**
- **~ 286 ´ 210 ´ 80 m**
- **180 ms time step**
- **108-processor domain**



***w* (m/s)**

Surface vibration from idealized vehicle forces

<u>Propagation Features</u>

Effects of

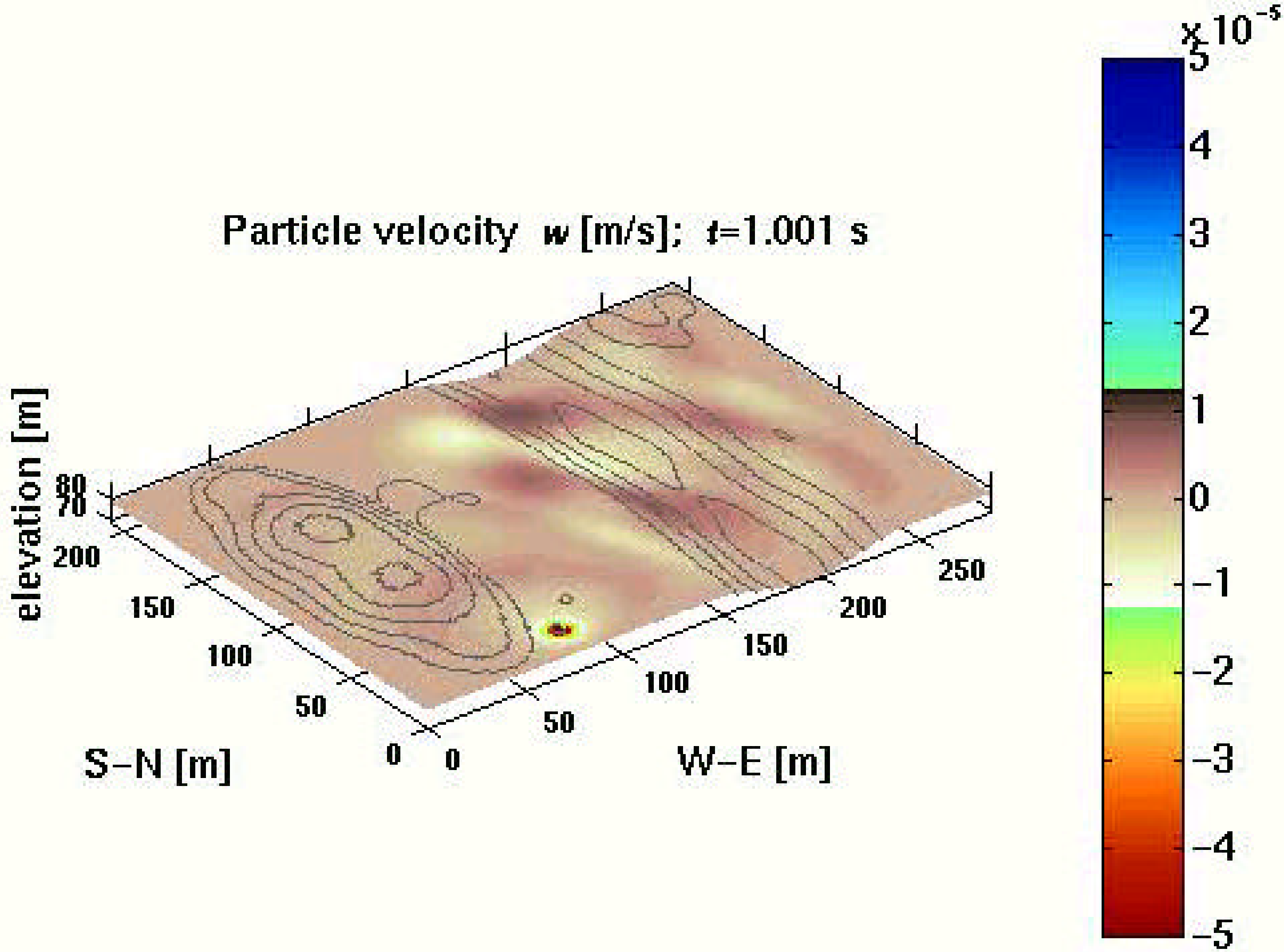
•Vehicle speed

•Shallow bedrock

•Ravine and water table

•Outcrop

•Material damping



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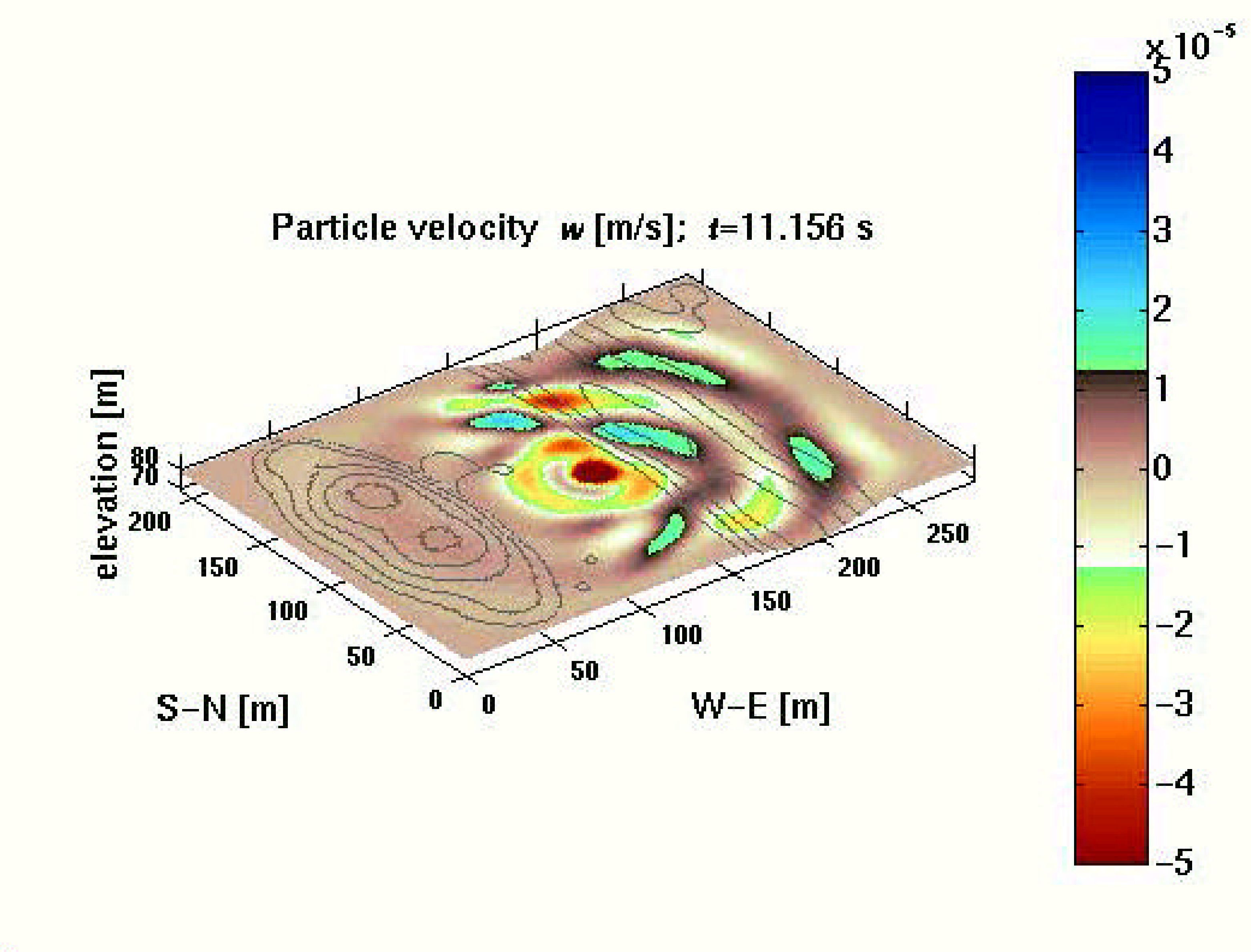
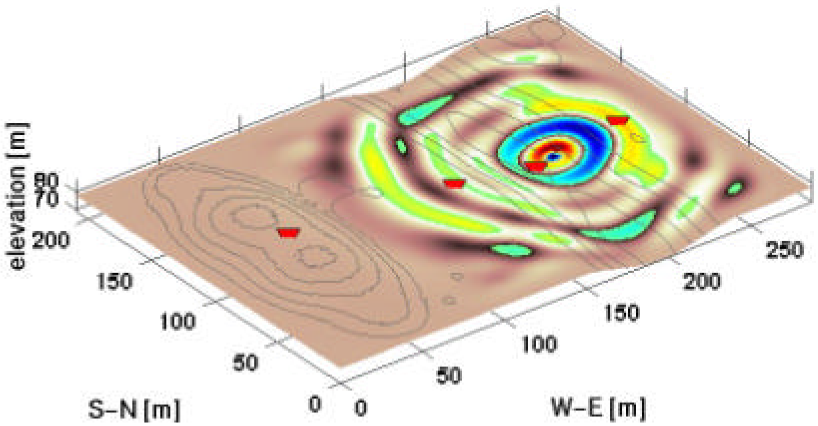
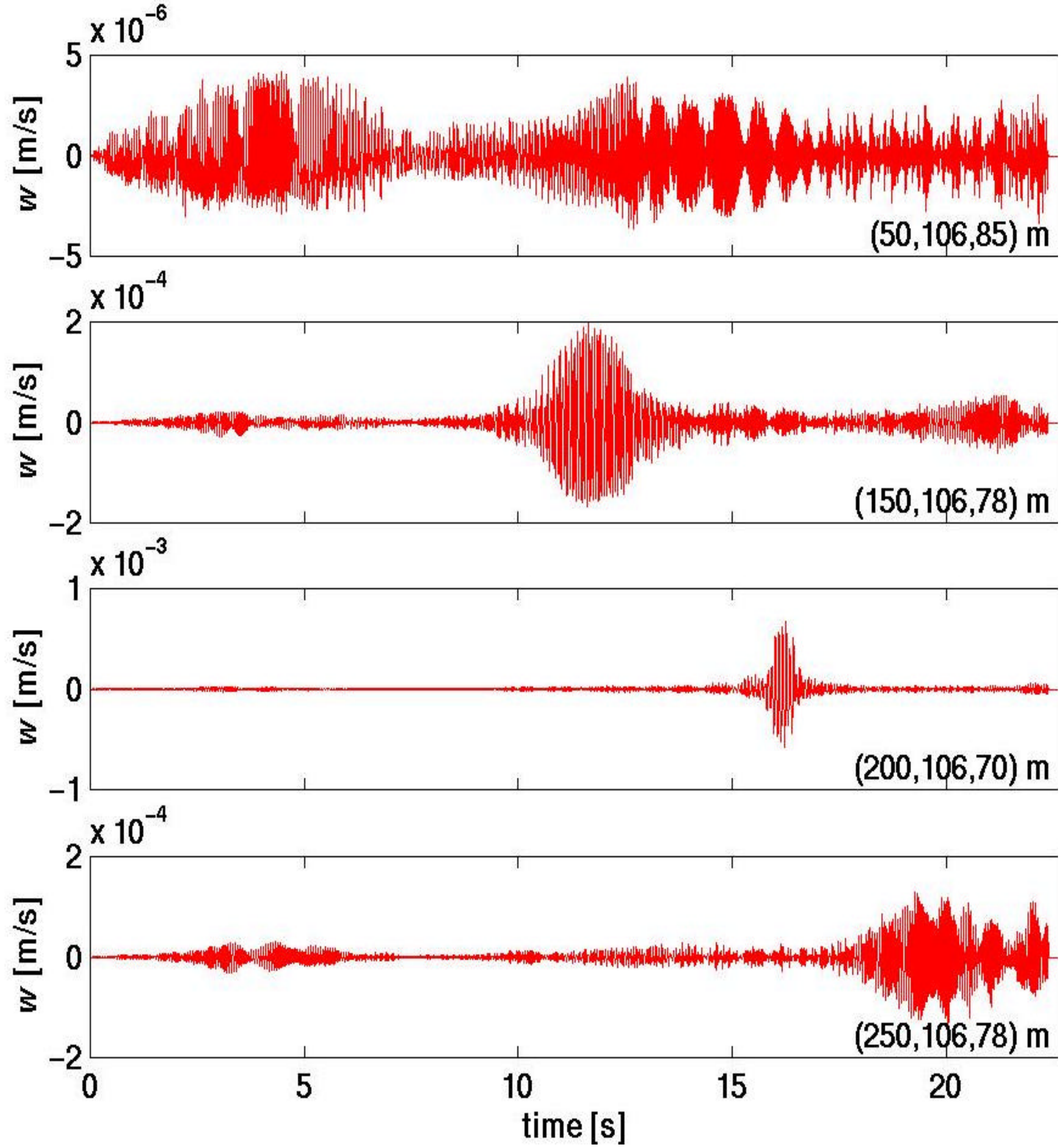


Vertical particle velocity from idealized vehicle at four “receiver” locations

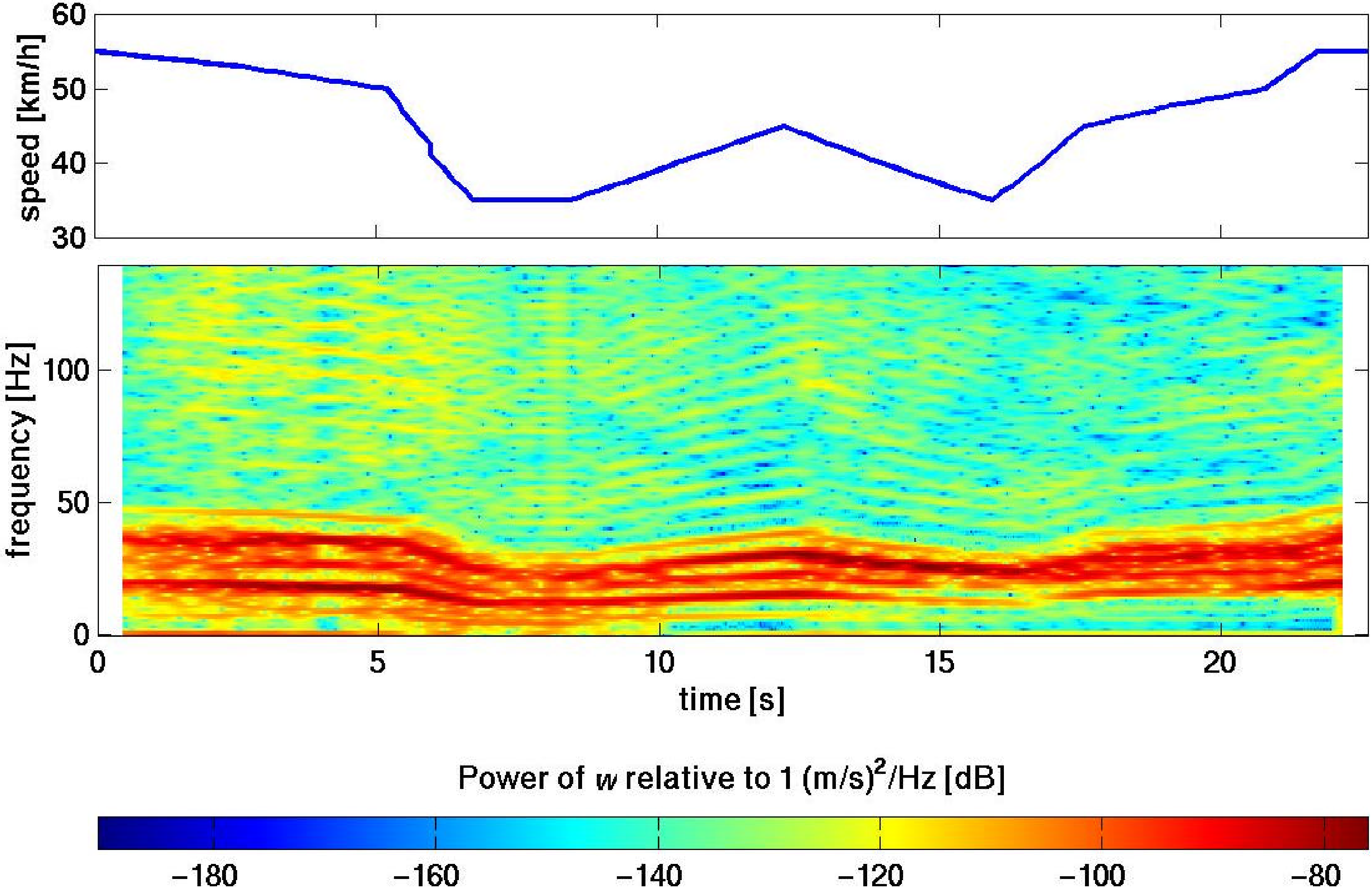




The seismic wave field history

- **allows placement of virtual sensors at any point in the simulation domain**
- **allows ground sensor networks to be simulated**

Spectrogram of *w* signal from idealized vehicle at outcrop receiver



Movement of M1A1 in vehicle dynamics/ ground force prediction computation

Features

•**Turn at 4-5 seconds**

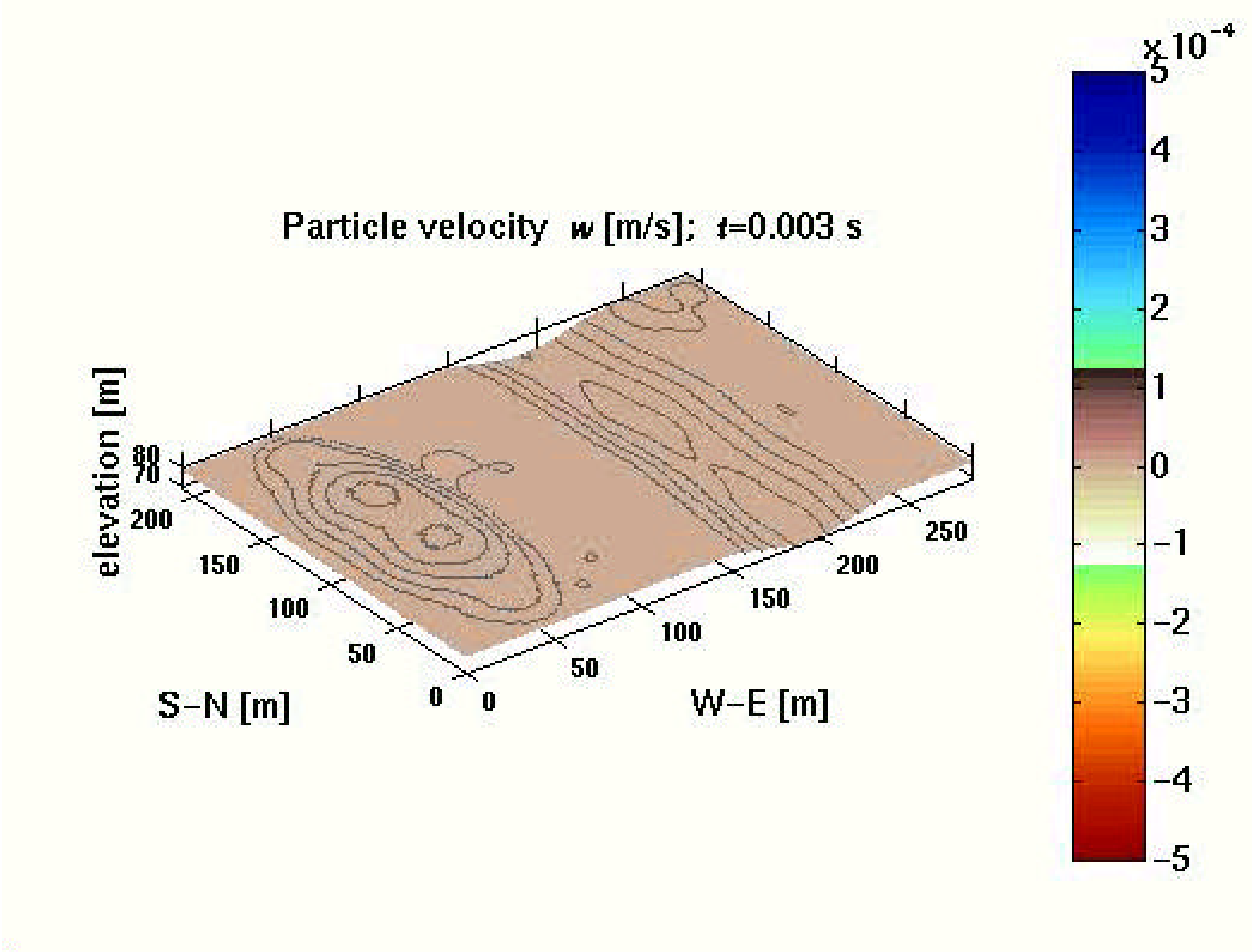
Surface vibration from M1A1 model forces

<u>Propagation Features</u>

Effects of

•Higher frequency input

•Turn of vehicle

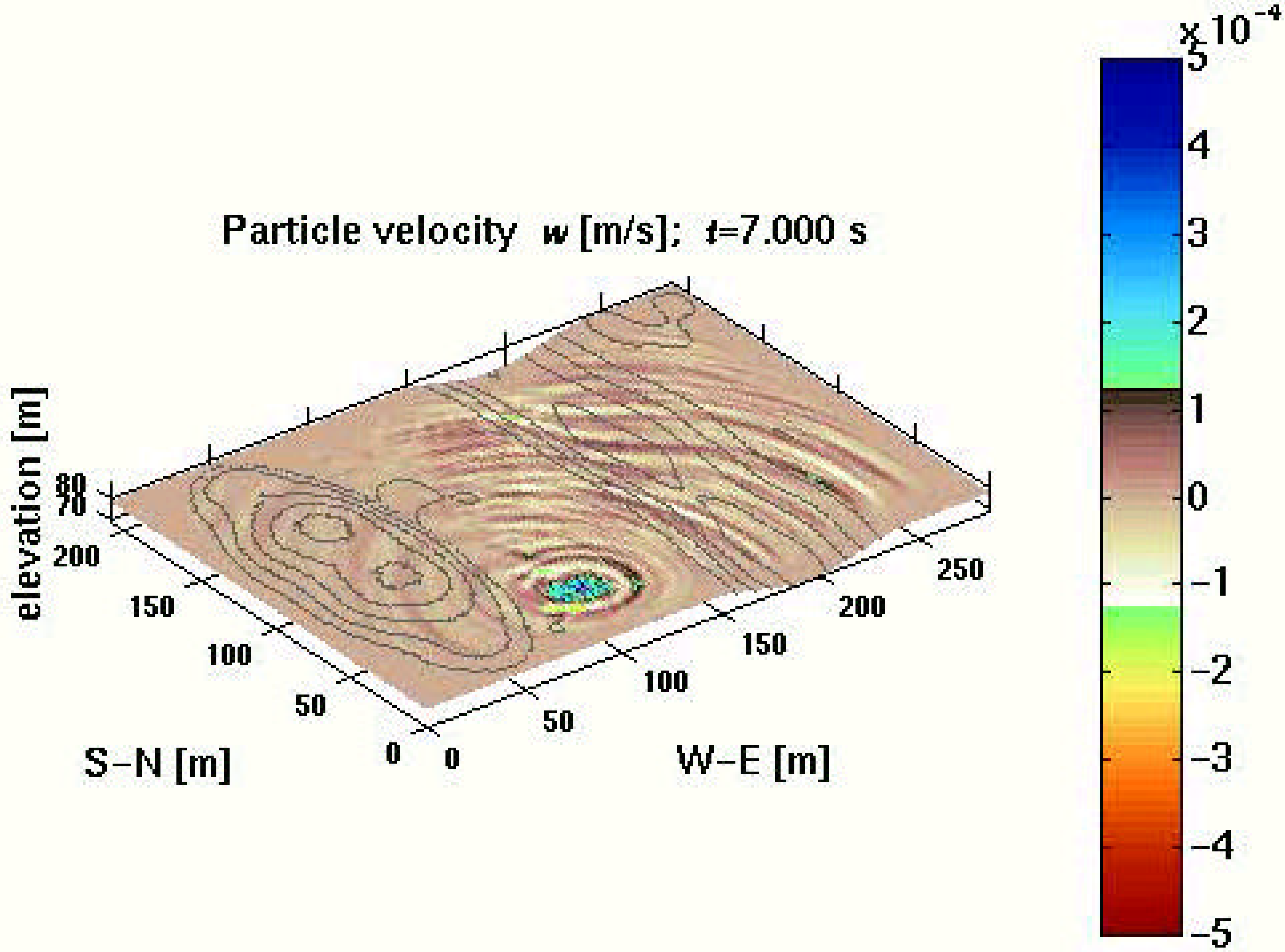


Surface vibration from M1A1 model forces

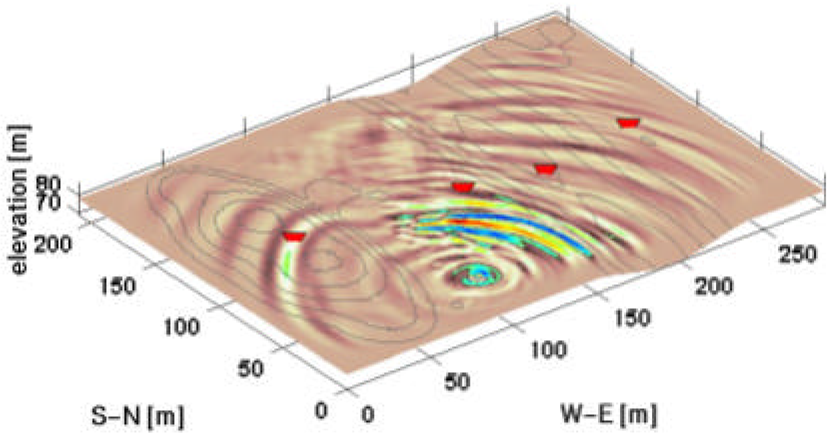
Propagation Features

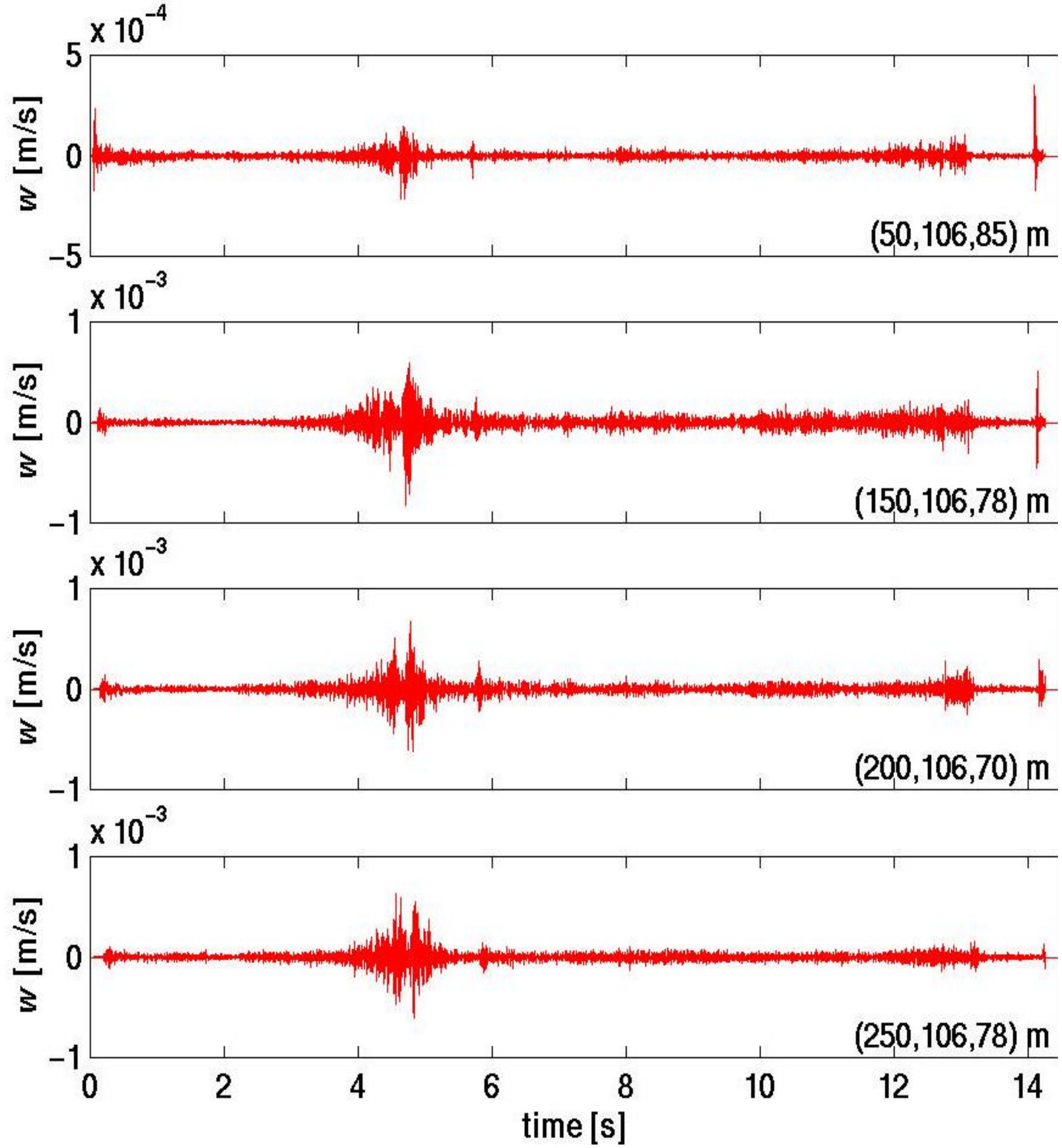
Effects of

- **Higher frequency input**
- **Turn of vehicle**

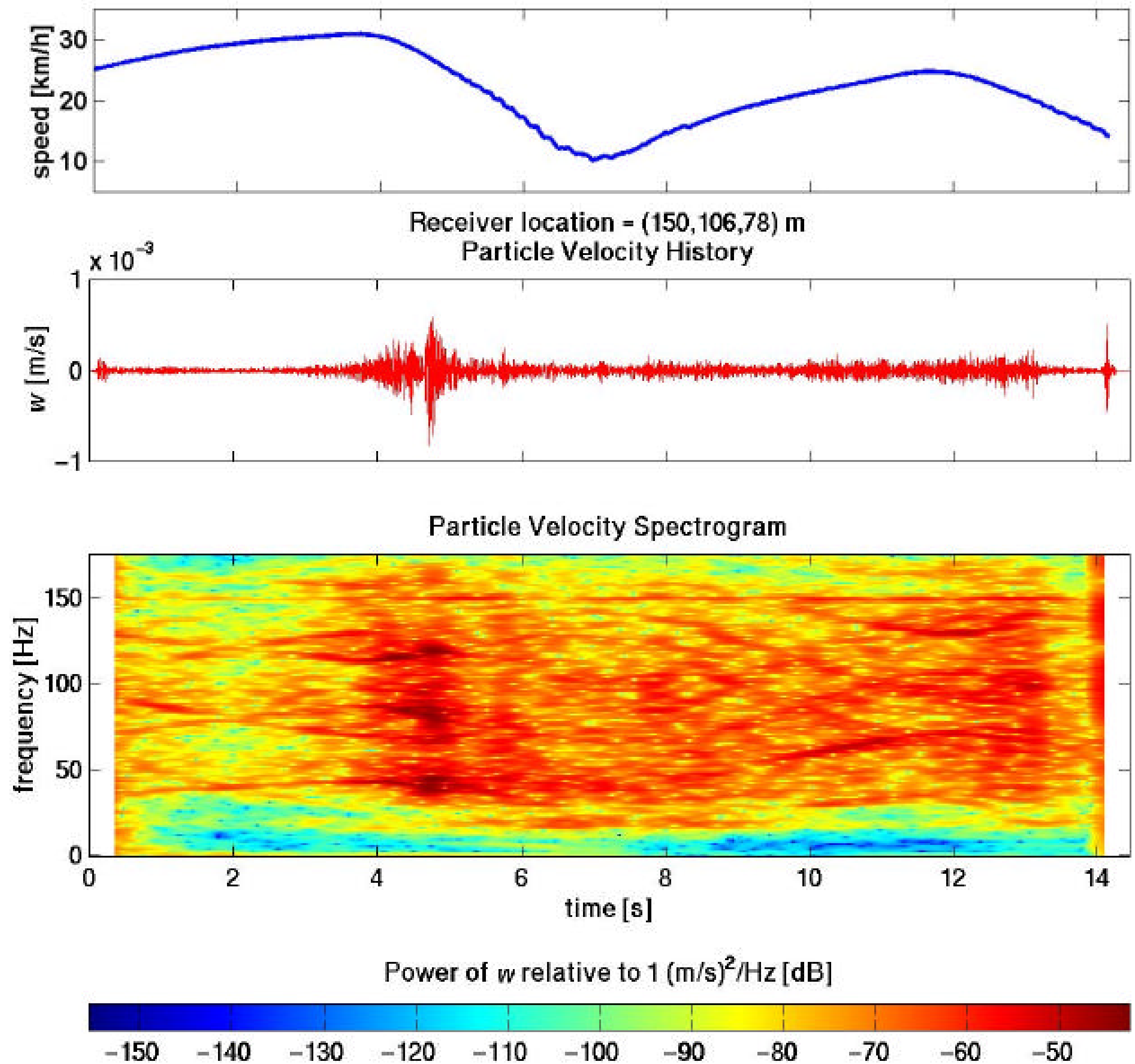


Vertical particle velocity from M1A1 model forces at four “receiver” locations

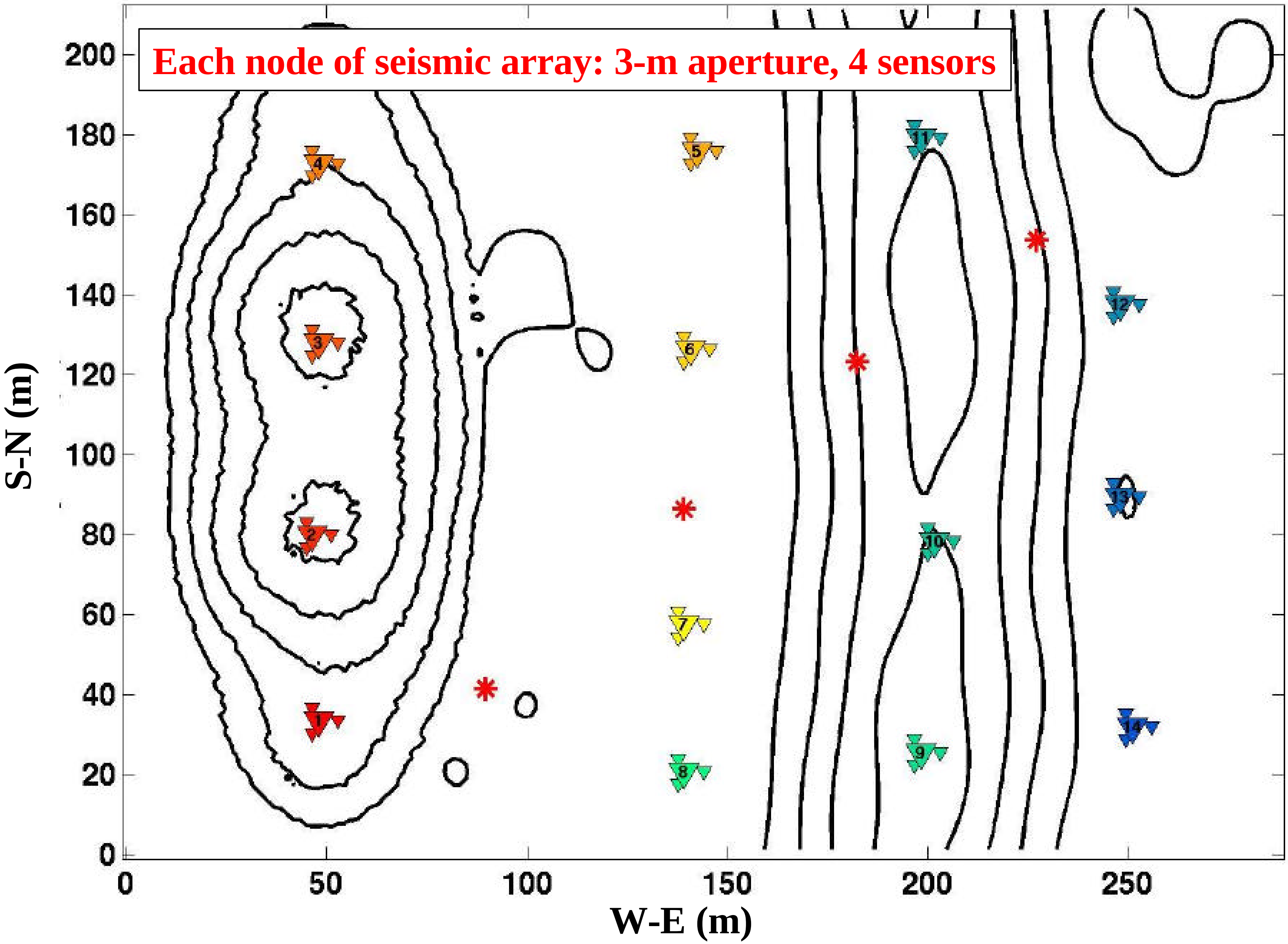




Spectrogram of *w* signal from M1A1 model at receiver between outcrop and trench



Virtual deployment of UGS seismic network

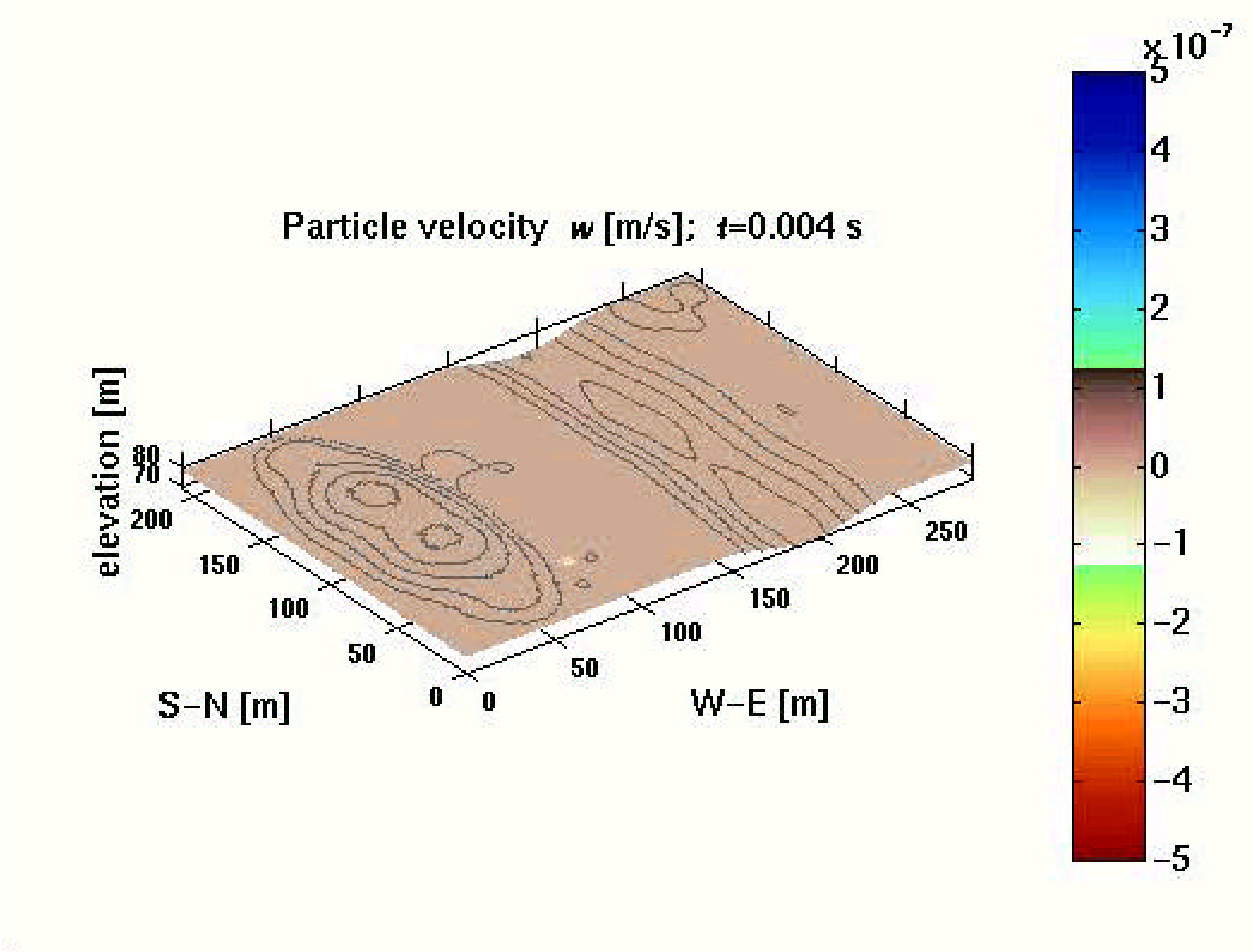


Surface vibration from calibration forces

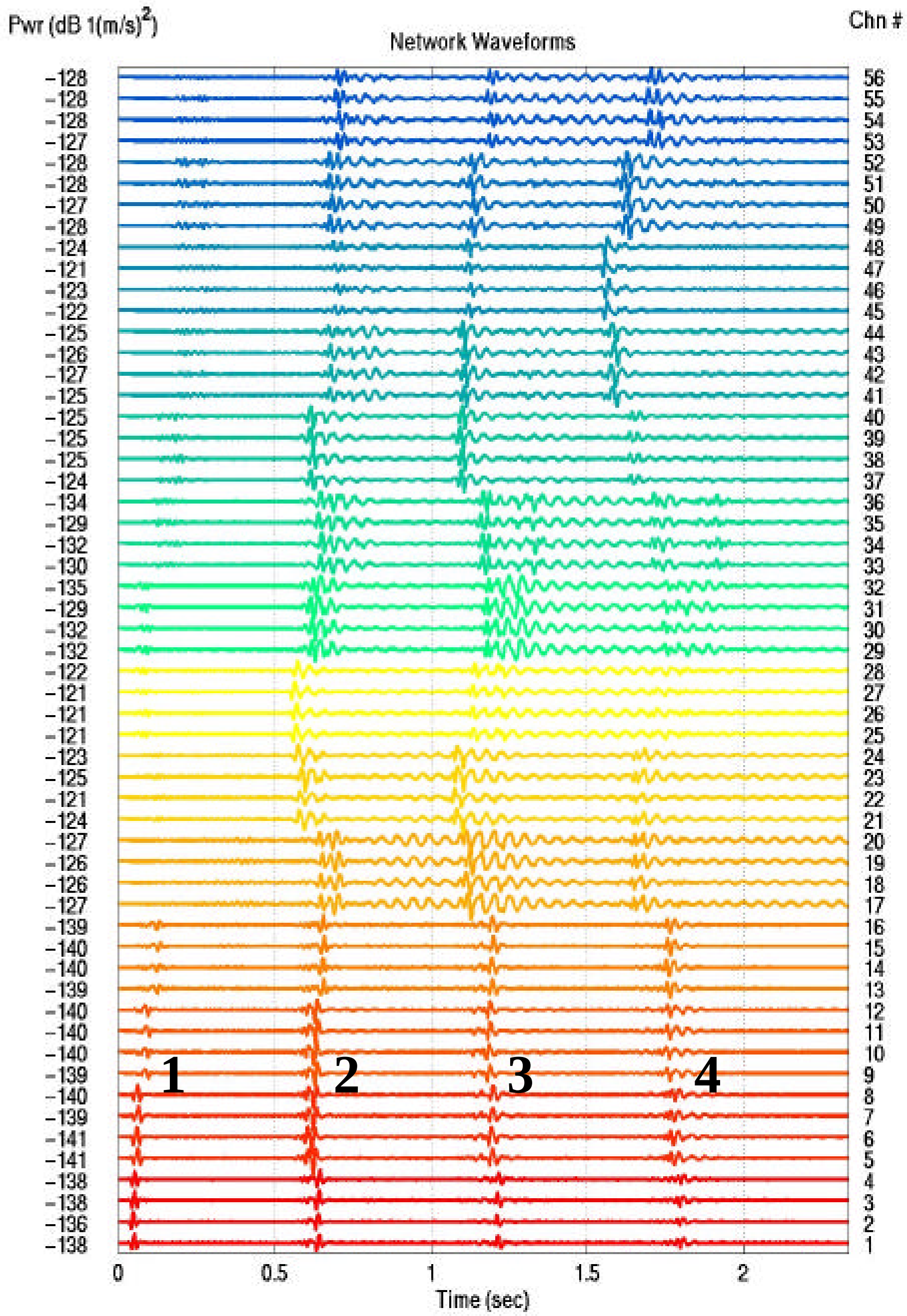
Propagation Features

Effects of

•Dropping calibration "stones" out of helicopter



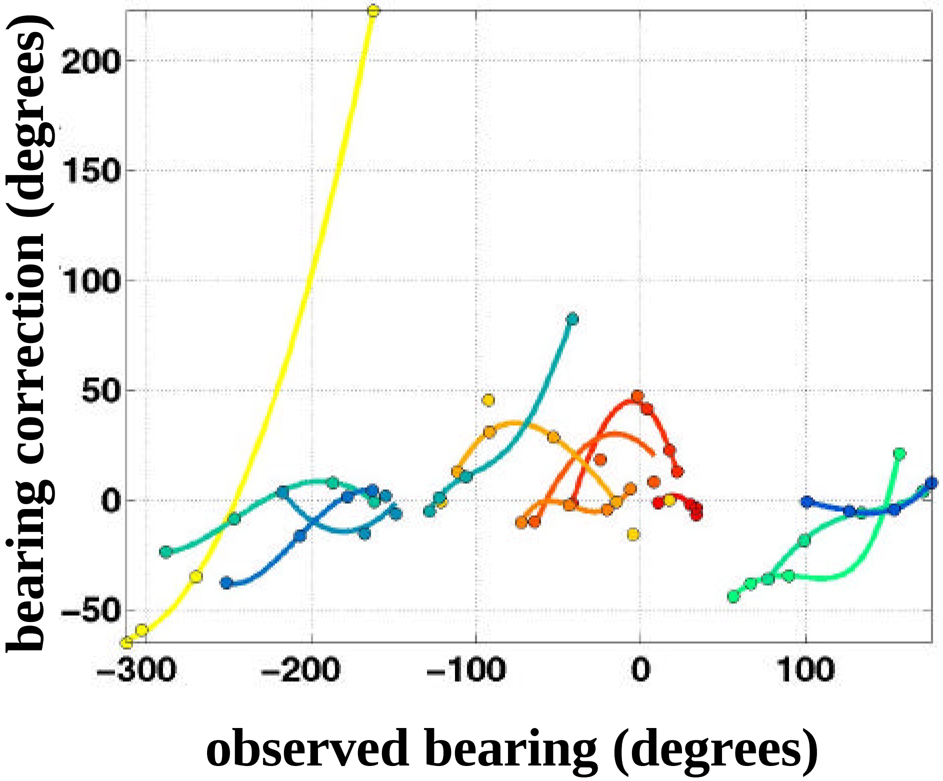
Calibration data recorded by seismic network



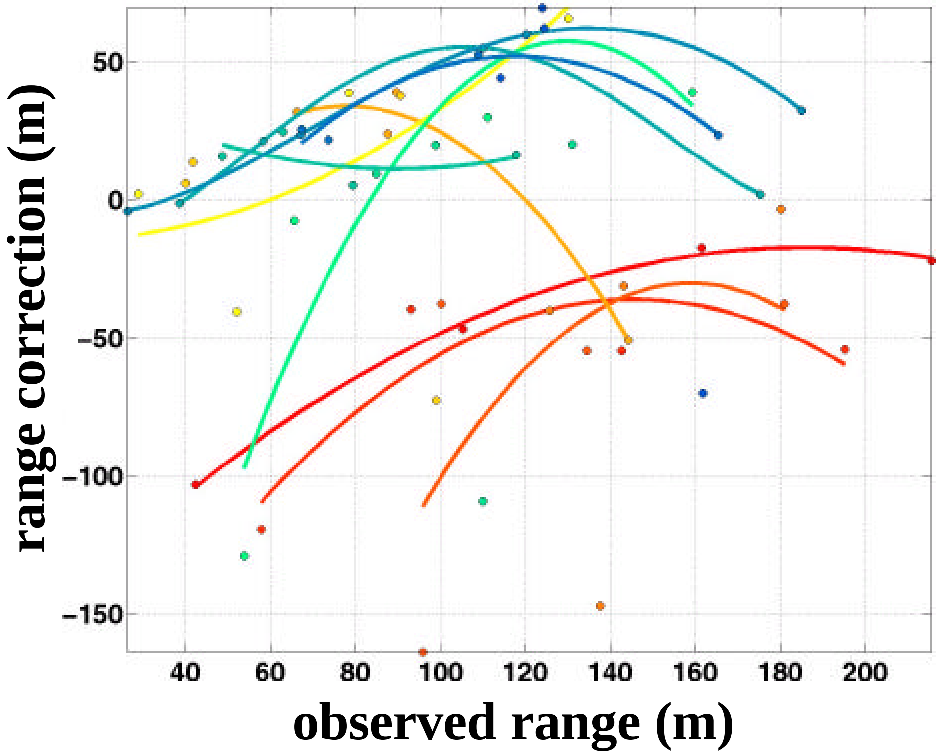
Four calibration events:
known location, time, and magnitude

Note changes in character
of each calibration event

Corrections calculated by seismic network

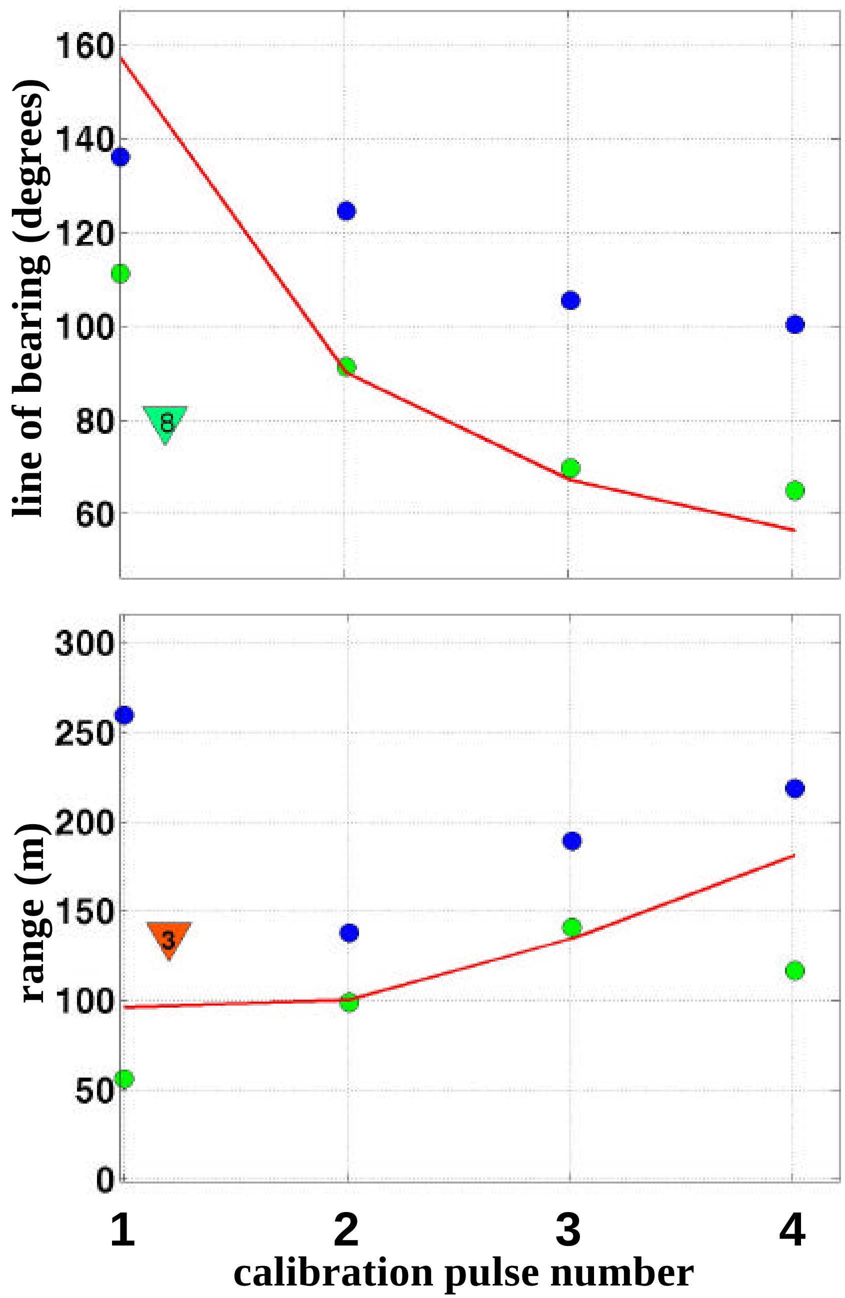


Method for LOB is NARROWBAND 2-D beamformer



Method for ranging is BROADBAND exponential decay algorithm

Example corrections to calibrated pulse locations

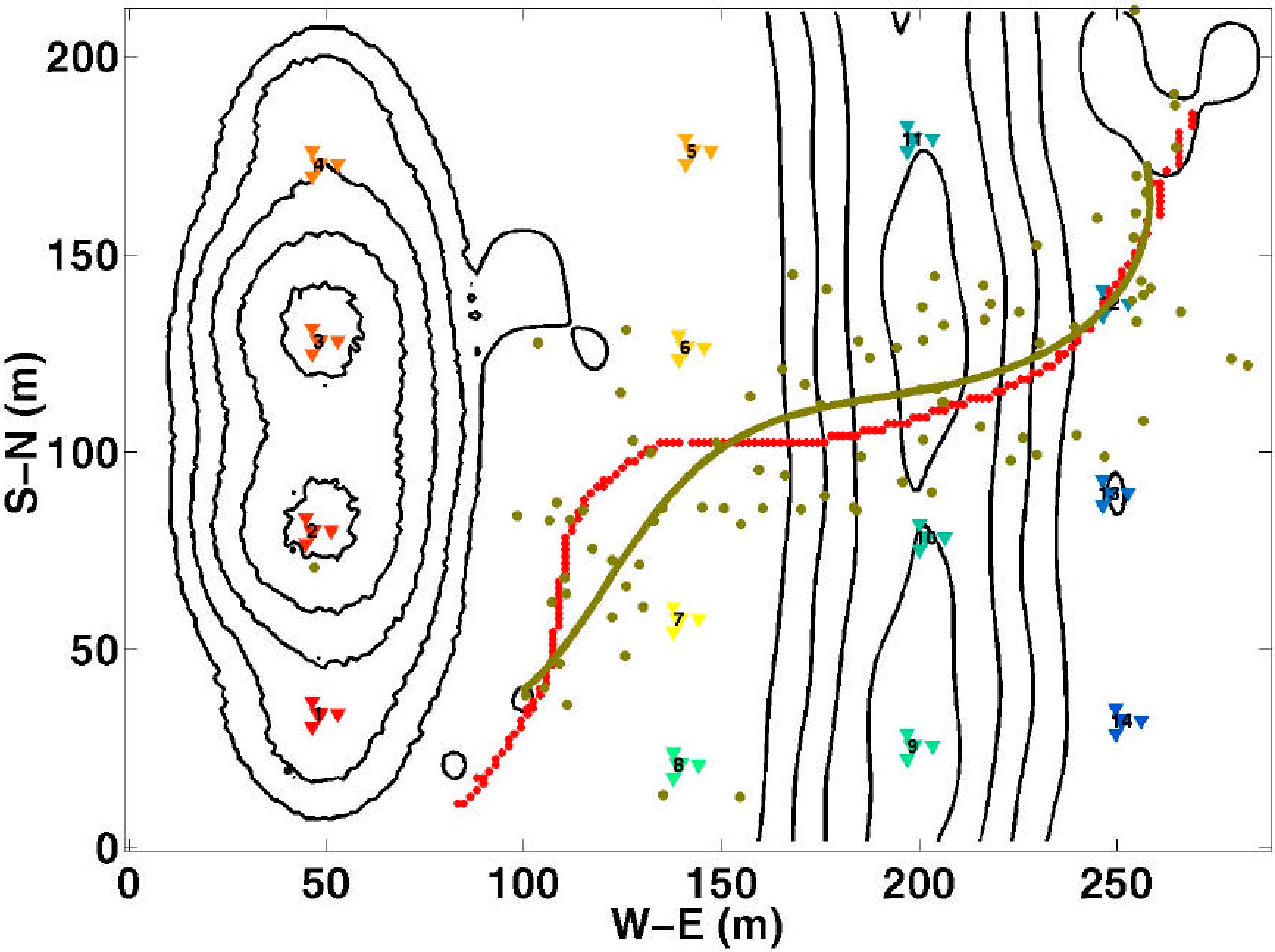


Red line: true lob/range from node to calibration pulse

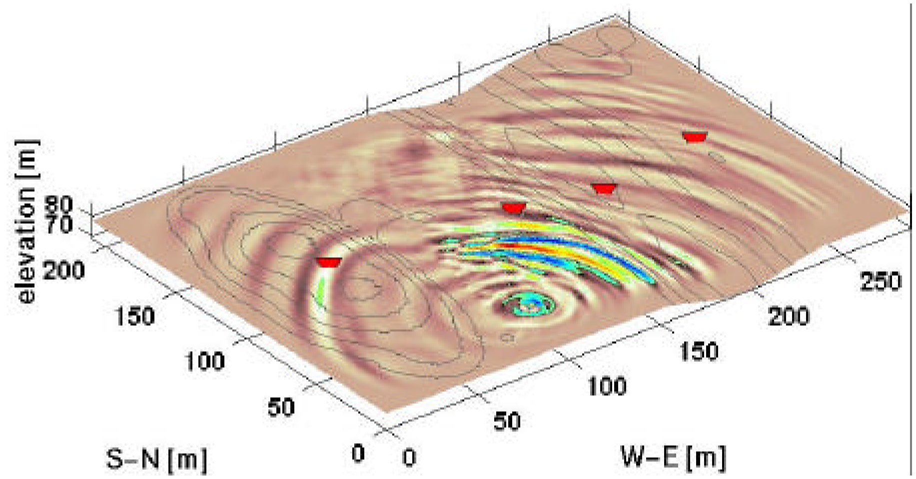
Blue circle: estimated lob/range from node to calibration pulse based on raw data

Green circle: corrected lob/range from node to calibration pulse based on geologic adaptation

Adapted network tracking performance

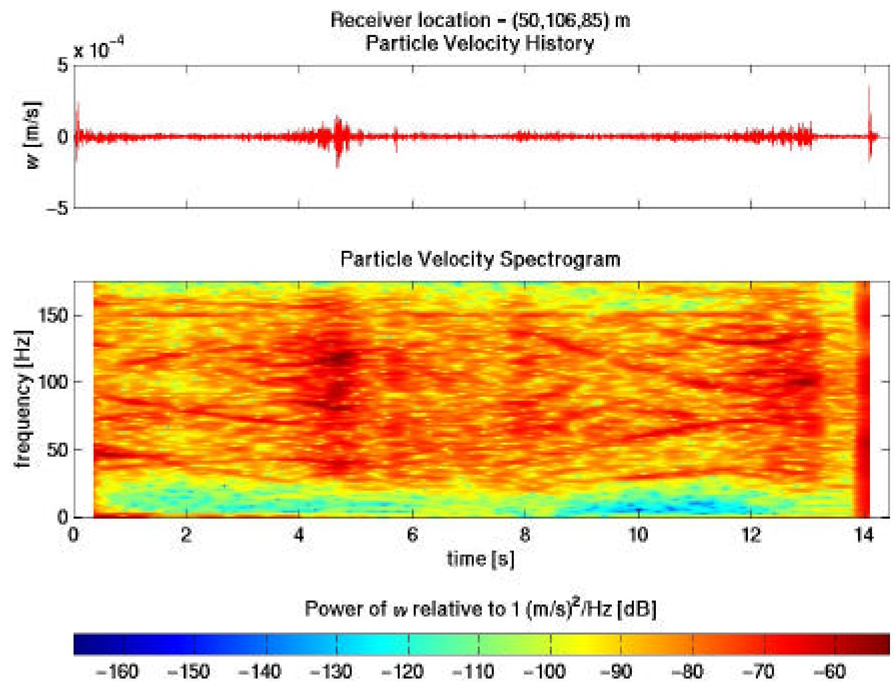


Summary



The moving vehicle simulations:

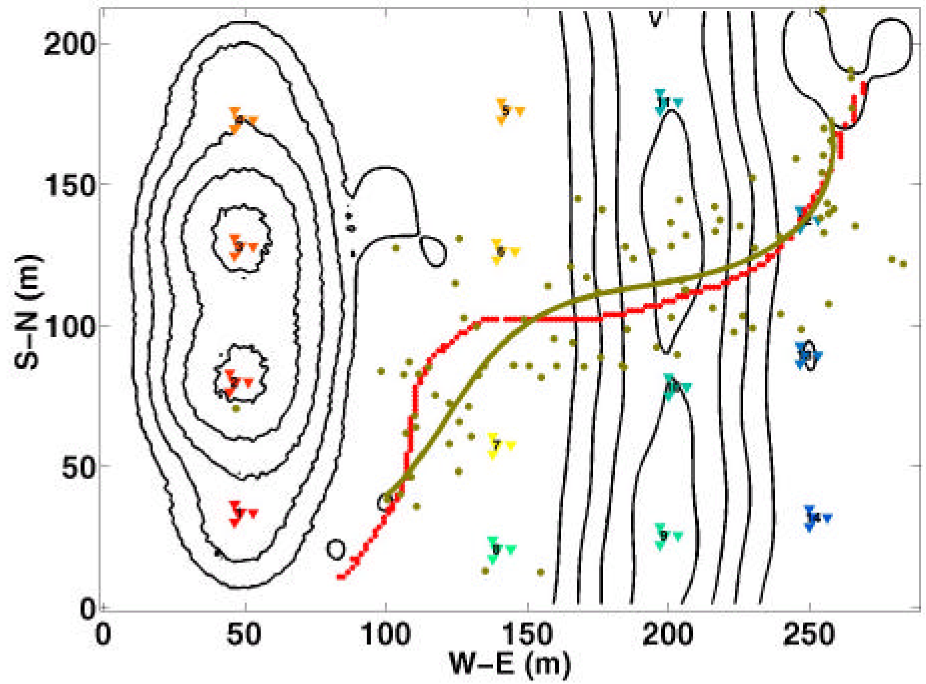
- **produce realistic and expected results**
- **produce seismic vehicle signatures with features of measured signatures**
- **are the first such simulations**



Summary, continued

Example applications:

- Demonstrate use of the simulations for system development and user situational awareness
- Are the first high population UGS network tracking results of their kind
- Demonstrate method for uniquely adapting UGS network to environment



Conclusion

These results provide a strong indication that simulations have a role in seismic system development and acquisition

Their impact can be seen as:

- **reducing system costs and development time**
- **improving system performance in complex environments**
- **allowing propagation physics to be incorporated into system algorithms**